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Evaluation of ultrasound imagery and body shape to predict carcass and fillet yield in farm-raised catfish

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ABSTRACT: Accurate prediction of meat yield in live animals may allow more efficient genetic improvement of meat yield in farm-raised catfish. An initial trial with 30 channel catfish demonstrated significant correlations among weight-adjusted residuals for muscle area measured from transverse ultrasound images and transverse sections at five locations along the trunk musculature (r = 0.30 to 0.70). Relationships of weight-adjusted residuals for three meat yield traits (carcass, whole fillet, and shank fillet) with weight-adjusted residuals for 15 external body shape measurements and five transverse ultrasound measurements of muscle area were determined for 51 female and 91 male channel × blue catfish backcross hybrids. Compared to males, females had smaller heads; deeper, wider, shorter bodies; larger ultrasound muscle area; and higher meat yield. Correlations between carcass traits and body shape and carcass traits and ultrasound measurements were generally higher for females than for males. Correlations among carcass traits and ultrasound muscle area were typically higher than correlations among carcass traits and external body shape in both sexes. A single ultrasound measurement explained 40 to 50% and 16 to 23% of the variation in meat yield traits of females and males, respectively. The best three-variable model using ultrasound and body shape traits explained 48 to 56% and 31 to 38% of the variation in meat yield traits in females and males, respectively. Differences between males and females for the variability in meat yield traits explained by the models may be related to sexual dimorphism for body shape and fillet yield observed in catfish. Ultrasound has potential for predicting meat yield in live fish, but improved prediction accuracy is needed. Differences in meat yield traits between males and females and among individuals within sexes suggest that selecting for fish with smaller heads and deeper, shorter body shape posterior to the visceral cavity will increase meat yield in catfish.

Key Words: Fish, Meat Yield, Prediction, Ultrasound

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Introduction

Commercial catfish farming is the largest aquaculture industry in North America; over 250 million kg of catfish was processed in 1998 (USDA 1999). Processed catfish are typically sold as dressed carcasses (head, viscera, and skin removed) or boneless fillets. Therefore, increasing meat yield (carcass or fillet) will result in more retail product per unit weight of live fish produced and will benefit the catfish farming industry.

Improvements in carcass yield through selective breeding have been achieved in other livestock species, and selection for increased meat yield in catfish should be possible. However, selection for meat yield is hindered because direct measurement of carcass traits requires that the animal be killed and removed from the pool of potential breeders. Development of accurate, quick, and nondestructive methods to predict meat yield in live fish could improve selection efficiency and allow more rapid genetic improvement of catfish meat yield.

Ultrasound imagery and body shape have been used to predict meat yield of live animals in cattle (Busch et al., 1969; Shepard et al., 1996; Bergen et al., 1997), swine (Gresham et al., 1994; Cisneros et al., 1996), and sheep (Berg et al., 1996), and it may be possible to predict meat yield in farm-raised catfish with similar techniques. Predicted meat yield could be used to identify breeding stock with higher meat yields. Thus, the objective of this study was to determine the relationships between meat yield traits and body shape and

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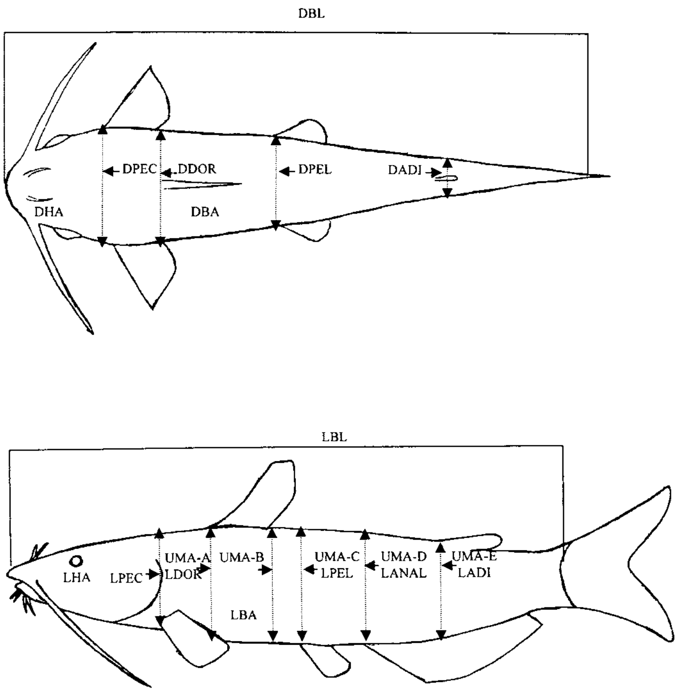

Figure 1. Location of ultrasound (UMA-A through E) and body shape measurements recorded for catfish. Definitions for abbreviations are included in the text and Table 1.

transverse ultrasound images of muscle area measured in live catfish.

Materials and Methods

Data Collection

An initial study was conducted with 30 market-weight channel catfish (mean weight 811 g, range 535 to 967 g) to compare muscle area measured from transverse ultrasound images with muscle area measured from transverse sections cut from the same fish. Fish were killed by overdose with tranquilizer (2% tricaine-methylsulfonate), weighed, and placed in water in a polyethylene container (95 cm long × 35 cm wide × 30 cm deep). A technician held the fish suspended in the water while an experienced radiologist used an Aloka 1700 ultrasound unit equipped with a 5-MHz linear array transducer to record transverse ultrasound images. The probe was placed in the water and ultrasound images of the left-side muscle area (**UMA**) were recorded at five positions on each fish: anterior insertion of the dorsal fin (**UMA-A**), posterior insertion of the dorsal fin (**UMA-B**), insertion of the pelvic fin (**UMA-C**), anterior insertion of the anal fin (**UMA-D**), and anterior insertion of the adipose fin (**UMA-E**) (Figure 1). A small drop of cyanoacrylate (Super Glue, Super Glue Corp., Hollis, NY) was used to attach a 1-cm long section of 0.3-mm-diameter catheter tubing to the fishes' skin, perpendicular to the long axis of the body, to serve as a visible landmark at each ultrasound location. Video output from the ultrasound unit was routed to a PC for image storage. Real-time ultrasound images were viewed and, when an acceptable image (proper orientation, location, and clarity) was produced, the image was captured, labeled with ultrasound position, and saved.

After ultrasound images were recorded, fish were frozen for 24 h at –20°C. A bandsaw was used to cut transverse sections through the frozen fish at the same anatomical points at which ultrasound images had been collected. Frozen sections were thawed and placed on a gray background with a 5-cm rule as a size reference, and images were captured with a CCD video camera (Sony, Model XC-57) and saved. Left-side muscle area was measured from ultrasound and frozen sections images using image analysis software (Image-Pro Plus, Media Cybernetics, Silver Springs, MD).

In the second phase of the study, 55 female (mean weight 665.3 g) and 95 male (mean weight 786.3 g) channel catfish × blue catfish backcross hybrids (channel catfish female × [channel catfish × blue catfish F_1 male]) from a common tank were used to determine relationships of three carcass traits: carcass weight (head, viscera, and skin removed), total fillet weight (deboned muscle), and shank fillet weight (remaining fillet after removal of belly meat). Fifteen body shape traits and five measurements of muscle area from transverse ultrasound scans were used.

Fish were tranquilized with 0.2% tricaine methylsulfonate and an individually coded radio frequency tag (BioMark, Buhl, ID) was inserted into the dorsal musculature of each fish to allow identification of fish throughout the study. Fish were placed in the previously described container with water and tranquilizer. Two alligator clips were anchored to each of the container's long sides and one alligator clip was anchored to each end of the container by length-adjustable nylon string. Clips were attached to fin margins, and string tension was adjusted to provide consistent positioning of the fish. A small drop of cyanoacrylate was used to fix a 5-cm rule to each fish's skin as a size reference; dorsal and lateral images of each fish were recorded with a CCD video camera, and images were saved. Body shape measurements were determined using the previously described image analysis software. Dorsal view measurements included head area (**DHA**), body area (**DBA**), body length (**DBL**; anterior tip of upper jaw to posterior termination of caudal musculature), body width at the pectoral fin insertion (**DPEC**), body width at the anterior insertion of the dorsal fin (**DDOR**), body width at the pelvic fin insertion (**DPEL**), and body width at the anterior insertion of the adipose fin (**DADI**) (Figure 1). Lateral view measurements included head area (**LHA**), body area (**LBA**), body length (**LBL**), body depth at the pectoral fin insertion (**LPEC**), body depth at the anterior insertion of the dorsal fin (**LDOR**), body depth at the pelvic fin insertion (**LPEL**), body depth at the anterior insertion of the anal fin (**LANAL**), and body

Table 1. Description of abbreviations used in the text

Abbreviation	Description
Muscle Area Measurements	
UMA-A	Ultrasound left-side muscle area at the anterior insertion of the dorsal fin
UMA-B	Ultrasound left-side muscle area at the posterior insertion of the dorsal fin
UMA-C	Ultrasound left-side muscle area at the insertion of the pelvic fin
UMA-D	Ultrasound left-side muscle area at the anterior insertion of the anal fin
UMA-E	Ultrasound left-side muscle area at the anterior insertion of the adipose fin
FSMA (A–E)	Frozen-section left-side muscle area (corresponding to ultrasound locations)
Body shape, dorsal view	
DHA	Dorsal head area
DBA	Dorsal body area
DDOR	Body width at the anterior insertion of the dorsal fin
DPEC	Body width at the pectoral fin
DPEL	Body width at the pelvic fin
DADI	Body width at anterior insertion of the adipose fin
DBL	Dorsal body length
Body shape, lateral view	
LHA	Lateral head area
LBA	Lateral body area
LPEC	Body depth at the pectoral fin
LDOR	Body depth at the anterior insertion of the dorsal fin
LPEL	Body depth at the pelvic fin
LANAL	Body depth at the anterior insertion of the anal fin
LADI	Body depth at the anterior insertion of the pelvic fin
LBL	Body length

depth at the anterior insertion of the adipose fin (**LADI**) (Figure 1). Definitions for abbreviations used in the text are listed in Table 1.

Following recording of body shape, fish were placed in tanks with flow-through well water and allowed to recover overnight. The following day fish were tranquilized (0.2% MS-222) and ultrasound images were recorded using the previously described techniques and locations, except that a Toshiba Echocee ultrasound unit with a 7.5-MHz convex array transducer was used during this portion of the study. After collecting ultrasound images, fish were allowed to recover in tanks supplied with flow-through well water overnight. The following morning fish were killed by overdose with 2% tricaine methylsulfonate, viscera were removed by hand, heads were removed with a catfish-heading machine (Barth Design, Buhl, ID), and skin was removed with a skinning machine (Collum Tool, Greenville, MS). Headless, skinless, eviscerated carcasses were filleted by an experienced employee from a catfish processing plant. Data recorded during processing included whole weight, sex, carcass weight, total fillet weight, and shank-fillet (belly flap removed) weight.

Data Analysis

Means and standard deviations for left-side ultrasound muscle area (UMA) and left-side frozen section muscle area (**FSMA**) for the 30 channel catfish were determined. Weight-adjusted residuals for UMA and FSMA were derived by linear regression of muscle area on whole fish weight (SAS Inst. Inc., Cary, NC). Correlations among unadjusted values for UMA and FSMA and correlations among weight-adjusted residuals for UMA and FSMA were determined (Correlation Procedure, SAS) for each anatomical position.

Analysis of covariance (GLM procedure, SAS) with whole weight as a covariate was used to compare means

Table 2. Means, standard deviations, correlations, and weight-adjusted residual correlations for ultrasound left-side muscle area (UMA) and frozen section left-side muscle area (FSMA) measured at five locations in 30 channel catfish (mean weight = 811 g)

Location	UMA	SD	FSMA	SD	Correlation between UMA and FSMA	Residual correlation between UMA and FSMA
UMA-A, cm^2	9.98	1.74	10.35	1.9	0.84	0.57
UMA-B, cm^2	11.23	1.83	11.73	2.02	0.91	0.30
UMA-C, cm^2	13.20	1.96	13.49	2.21	0.94	0.60
UMA-D, cm^2	11.06	1.75	10.97	1.66	0.94	0.70
UMA-E, cm^2	5.71	0.87	5.52	0.99	0.91	0.53

Table 3. Means, standard deviations, and weight-adjusted residual standard deviations for total weight, carcass traits, body shape measurements, and left-side ultrasound muscle area measurements in male and female channel catfish × blue catfish backcross hybrids

Trait	Female	SD	Residual SD	Male	SD	Residual SD
Total weight, g	665.3	158.2	—	786.3	190.4	—
Carcass weight, g	415.1	95.3	12.7	473.4	115.3	17.1
Total fillet weight, g	178.3	41.9	7.8	204.6	52.0	11.4
Shank fillet weight, g	148.5	35.1	6.1	168.7	42.6	9.2
Ultrasound						
UMA-A, cm^2	8.48	1.53	0.80	9.92	1.92	1.00
UMA-B, cm^2	9.91	2.07	1.07	10.91	1.86	0.71
UMA-C, cm^2	11.43	2.16	0.73	12.45	2.02	0.74
UMA-D, cm^2	10.30	2.08	0.51	10.73	1.85	0.62
UMA-E, cm^2	5.45	0.95	0.42	5.55	0.95	0.55
Lateral view measurements						
LBL, cm	36.7	2.3	1.0	38.7	2.9	1.0
LPEC, cm	5.6	0.4	0.2	6.0	0.5	0.3
LDOR, cm	6.7	0.5	0.3	7.2	0.6	0.3
LPEL, cm	6.8	0.6	0.3	7.1	0.6	0.2
LANAL, cm	7.3	0.6	0.3	7.5	0.6	0.3
LADI, cm	5.5	0.5	0.2	5.6	0.5	0.3
LHA, cm^2	32.5	4.5	2.4	37.7	7.0	3.2
LBA, cm^2	167.4	24.0	6.3	183.8	27.1	4.7
Dorsal view						
DBL, cm	34.8	2.3	1.1	36.4	2.9	1.2
DPEC, cm	7.4	0.6	0.3	7.9	0.7	0.3
DDOR, cm	5.3	0.5	0.2	5.8	0.6	0.2
DPEL, cm	4.9	0.5	0.2	5.0	0.5	0.2
DADI, cm	2.6	0.2	0.1	2.6	0.2	0.1
DHA, cm^2	42.8	6.7	3.1	50.4	8.6	3.6
DBA, cm^2	104.2	16.1	4.8	112.9	19.2	6.2

Ultrasound measurements are based on 51 females and 91 males, and body shape measurements are based on 43 females and 73 males.

of males and females for carcass traits, body shape traits, and UMA. Weight-adjusted residuals for all traits were derived by linear regression of traits on whole fish weight, and residuals were used in all subsequent analysis. Relationships between whole fish weight and various other traits measured in this study were also analyzed with quadratic, cubic, and log-transformed models, but for the size range of fish used, a linear model had equivalent or higher R^2 values than other models tested. Relationships among carcass traits, body shape traits, and UMA were analyzed for males and females separately because means of traits and the regression coefficients for traits with whole weight sometimes differed between sexes. Correlations of carcass trait residuals with body shape trait and UMA residuals were determined (Correlation Procedure, SAS).

Carcass trait residuals were regressed on body shape and UMA residuals. Stepwise regression procedures (Stepwise Procedure, SAS) were used to select the best (highest R^2) single-variable models based on body shape traits, the best single-variable models based on UMA, and the best three-variable models based on body shape traits and UMA combined for carcass weight, total fillet weight, and shank fillet weight. The regression procedure was used to examine the data for outliers, determine regression coefficients, and determine adjusted R^2 values for selected regression models.

Results and Discussion

Ultrasound has been used to measure gonadal development in fish (Bonar et al., 1989, Blythe et al., 1995), but to our knowledge this is the first reported use of ultrasound to measure muscle area and correlate muscle area with fillet yield in fish. In large animals, palpation of internal anatomical features is commonly used to identify landmarks for determining ultrasound position (Herring, et al. 1994). However, due to the small size of catfish and the difficulty with palpating or imaging internal landmarks, catheter tubing fixed to the skin was used as a landmark. Catheter tubing landmarks were easy to apply, clearly visible on the image, did not affect image quality, and could be easily removed without harm to the fish.

Means for left-side muscle area in frozen sections (FSMA) and ultrasound images (UMA) measured at five locations in 30 channel catfish were not different ($P > 0.05$) and correlations among FSMA and UMA were significant, indicating that ultrasound images could be used to measure muscle area in catfish (Table 2). The highly significant correlations among unadjusted UMA and FSMA at the five locations (r = 0.84 to 0.94, $P <$ 0.001) were expected, given the large weight range of fish used (535 to 967 g). The correlations among weight-adjusted residuals for UMA and FSMA were lower (0.30 to 0.70) but still indicated that ultrasound detected variation in muscle area in addition to that associated with fish size. Residual correlations among UMA and FSMA we observed were similar to correlations among actual measurements and ultrasound measurements of longisimuss muscle area in cattle (Bergen et al., 1997; Perry and Fox, 1997) and swine (Smith et al., 1992; Gresham et al., 1994; Wood et al., 1994; Berg et al., 1996; Cisneros et al., 1996) (0.40 to 0.71) in studies using animals of similar weights or weight-adjusted residuals.

The channel catfish × blue catfish backcross was used in the second phase of the study because previous research has shown that channel × blue F_1 hybrids have higher carcass and fillet yield than purebred channel catfish (Yant et al., 1976; Dunham et al., 1987), and we were evaluating potential of improving meat yield by introgression of blue and channel catfish genomes. The three largest females and two largest males based on weight were identified as outliers and removed from the data set. One female and two males were removed due to data recording mistakes, resulting in 51 female and 91 male backcross hybrids being used in the study. The camera system used to record external images malfunctioned and no body shape data were recorded for 8 females and 18 males.

Means, standard deviations, and weight-adjusted residual standard deviations for traits measured in male and female backcross hybrids are listed in Table 3. Compared to males, females had higher ($P < 0.05$) least squares mean carcass weight (+14.0 g), total fillet weight (+5.5 g), and shank fillet weights (+6.3 g) (Table 4). Females were larger than males for traits related to the size of the posterior portion of the body: UMA-C (+0.40 cm^2), UMA-D (+0.96 cm^2), UMA-E (+0.50 cm^2), LANAL (+0.1 cm), LADI (+0.2 cm), DPEL (+0.2 cm) and DADI (+0.2 cm) and smaller than males for traits related to the size of the head and anterior portion of the body: UMA-A (–0.40 cm^2), LPEC (–0.1 cm), LDOR (–0.2 cm), LHA (–2.4 cm^2), DPEC (–0.2 cm), DDOR (–0.2 cm), DHEAD (–3.5 cm^2). Increased head size in male catfish is a secondary sexual characteristic associated with maturation (Dunham et al. 1987). The higher carcass and fillet yield observed in females compared to males in the backcross fish used in this study has been previously reported in purebred channel catfish (Park 1998). The differences between sexes for the traits measured suggest that the smaller heads; more shallow, narrow anterior body shape; and deeper, thicker posterior body shape of females were associated with their higher meat yield relative to males.

Table 4. Least squares means for carcass traits, body shape measurements, and left-side muscle area measurements in male and female channel catfish × blue catfish backcross hybrids.

Trait	Female	Male	SEM	
Carcass weight, g	461.4	447.4	***	2.1
Total fillet weight, g	198.5	193.0	***	1.3
Shank fillet weight, g	165.5	159.2	***	1.1
Ultrasound				
UMA-A, cm^2	9.1	9.5	*	0.13
UMA-B, cm^2	10.77	10.52		0.12
UMA-C, cm^2	12.43	12.03	**	0.09
UMA-D, cm^2	11.29	10.33	***	0.08
UMA-E, cm^2	5.87	5.37	***	0.07
Lateral view measurements				
LBL, cm	37.5	38.2	**	0.14
LPEC, cm	5.8	5.9	*	0.04
LDOR, cm	6.8	7.0	**	0.04
LPEL, cm	7.0	7.0		0.04
LANAL, cm	7.5	7.4	*	0.04
LADI, cm	5.7	5.5	*	0.04
LHA, cm^2	34.0	36.4	***	0.40
LBA, cm^2	176.6	178.3		1.1
Dorsal view				
DBL, cm	35.6	35.8		0.1
DPEC, cm	7.6	7.8	**	0.05
DDOR, cm	5.5	5.7	***	0.03
DPEL, cm	5.1	4.9	***	0.02
DADI, cm	2.7	2.5	***	0.01
DHA, cm^2	45.2	48.7	***	0.50
DBA, cm^2	110.3	109.1		0.80

Ultrasound measurements are based on 51 females and 91 males, and body shape measurements are based on 43 females and 73 males.
*, **, ***Significantly different between sexes at *$P < 0.05$, **$P <$ 0.01, ***$P < 0.001$.

Data from males and females were analyzed separately because of differences between sexes in traits and differences in regression coefficients for some traits on whole weight. Traits having significant correlations (± indicating positive or negative correlation) with all three meat yield traits included UMA-B (+), UMA-C (+), UMA-D (+), LDOR (+), LPEL (+), and LANAL (+) in females and UMA-C (+), UMA-D (+), UMA-E (+), LPEL (+), and LHA (–) in males (Table 5). Ultrasound muscle area measurements were generally more highly correlated with yield traits than with body shape traits in both sexes, and correlations among carcass traits and ultrasound measurements were generally stronger for females than for males (Table 5). The UMA-C and UMA-D traits were among the most highly correlated traits with carcass traits in both males (0.335 to 0.458) and females (0.392 to 0.681). The lower correlations of UMA-B with carcass traits may be related to the effects of the swim bladder on image quality. Catfish have an air-filled swim bladder located in the visceral cavity below the dorsal fin, and the swim bladder resulted in incomplete images and poorly defined tissue margins at UMA-B.

Body shape traits also were generally more highly correlated with carcass traits in females than in males, except for LHA, which was negatively correlated with carcass traits in males but not in females. Body shape traits measured from the lateral view were generally

Table 5. Weight-adjusted residual correlations among carcass traits, body shape, and ultrasound muscle area in male and female channel catfish × blue catfish backcross hybrids

	Females			Males		
Traits	Carcass weight	Total fillet weight	Shank fillet weight	Carcass weight	Total fillet weight	Shank fillet weight
Ultrasound muscle area						
UMA-A, cm^2	0.270*	0.194	0.132	0.028	0.067	0.070
UMA-B, cm^2	0.340*	0.345*	0.307*	0.065	0.139	0.149
UMA-C, cm^2	0.621***	0.593***	0.681***	0.335***	0.391***	0.395***
UMA-D, cm^2	0.444***	0.392***	0.470***	0.458***	0.335***	0.390***
UMA-E, cm^2	0.432**	0.176	0.276*	0.434***	0.274***	0.324**
Lateral view						
LBL, cm	−0.263	−0.372*	−0.399*	−0.047	−0.178	−0.138
LPEC, cm	0.192	0.040	0.066	−0.151	−0.236*	−0.218*
LDOR, cm	0.393**	0.358*	0.315*	−0.028	0.064	0.021
LPEL, cm	0.507**	0.428**	0.410**	0.256*	0.236*	0.229*
LANAL, cm	0.537***	0.419**	0.374*	0.290*	0.081	0.088
LADI, cm	0.458**	0.307*	0.268	0.201	−0.066	−0.067
LHA, cm^2	0.178	0.105	−0.004	−0.224*	−0.265*	−0.297*
LBA, cm^2	0.254	0.049	0.018	0.186	−0.047	−0.021
Dorsal view						
DBL, cm	−0.204	−0.205	−0.258	0.094	−0.003	0.028
DPEC, cm	0.1423	−0.036	−0.026	0.021	−0.020	0.006
DDOR, cm	0.186	0.062	−0.017	−0.045	0.062	0.056
DPEL, cm	0.366*	0.275	0.149	0.321*	0.227	0.198
DADI, cm	0.189	0.050	0.041	0.250*	0.131	0.158
DHA, cm^2	−0.206	−0.201	−0.219	−0.064	−0.134	−0.128
DBA, cm^2	0.162	0.057	0.006	0.096	0.040	0.058

Ultrasound measurements are based on 51 females and 91 males, and body shape measurements are based on 43 females and 73 males.

*, **, ***Correlation significantly different from 0 at $^*P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$.

more highly correlated with carcass traits than body shape traits measured from the dorsal view. Catfish have a consistent black coloration from the dorsal view and identification of fin insertions was difficult, which may have influenced our ability to consistently measure body shape traits from the dorsal view. Review of the correlations among carcass traits and ultrasound and body shape traits indicate that, within sex, fish with greater UMA-C, ULMSA-D, ULMSA-E, and deeper posterior body measurements tended to have higher meat yield.

Regression models with UMA-C as the only independent variable had adjusted R^2 of 0.40, 0.44, and 0.50 for female carcass weight, total fillet weight, and shank fillet weight, respectively (Table 6). In males, models with UMA-C as the independent variable had adjusted R^2 of 0.16 and 0.17 for total fillet weight and shank fillet weight, and a model with UMA-D as the independent variable had an R^2 of 0.23 for carcass weight. The best one-variable models based on body shape for females were carcass weight (LANAL; R^2 = 0.26), total fillet weight (LPEL; R^2 = 0.17), and shank fillet weight (LPEL; R^2 = 0.15). The best one-variable models based on body shape in males included carcass weight (DPEL; R^2 = 0.09), total fillet weight (LHA; R^2 = 0.09), shank fillet weight (LPEL; R^2 = 0.05). The best three-variable models for females were carcass weight (UMA-C, LANAL, LHA; R^2 = 0.54), total fillet weight (UMA-A, UMA-C, UMA-D; R^2 = 0.48), and shank fillet weight (UMA-A, UMA-C, UMA-D; R^2 = 0.56). The best three-variable models for males included carcass weight (UMA-D, LHA, LPEL; R^2 = 0.38), total fillet weight (UMA-C, LHA, DPEC; R^2 = 0.31), and shank fillet weight (UMA-C, UMA-D, LHA; R^2 = 0.31).

It is not clear why the model R^2 were higher for females than for males, but differences in model fit may be related to differences between sexes for body shape, meat yield, and the relationship of these traits to fish size. Head size increases in males as they reach maturity, and head size is generally more variable in males than in females. Therefore, the weaker relationship between ultrasound measurements of muscle area and meat yield in males relative to females may be related to a greater influence of head size on meat yield in males. Head shape traits were included in the best three-parameter models for meat yield in males but not in females. We may have been better at accurately measuring differences among fish for ultrasound muscle area than for head size, which could have resulted in the higher R^2 for females than for males.

Models were limited to one or three variables because to be useful in an applied breeding program measurements would need to be recorded and measured rapidly and efficiently on a large number of fish. Addition of

Table 6. Single- and three-variable regression models with maximum R^2 for carcass weight, total fillet weight, and shank fillet weight.[a]

	Males	Females
One variable		
Ultrasound		
Carcass	$y = 13.3 \times (UMA\text{-}D)$; $R^2 = 0.23$	$y = 11.2 \times (UMA\text{-}C)$; $R^2 = 0.40$
Whole fillet	$y = 6.46 \times (UMA\text{-}C)$; $R^2 = 0.16$	$y = 7.09 \times (UMA\text{-}C)$; $R^2 = 0.44$
Shank fillet	$y = 6.06 \times (UMA\text{-}C)$; $R^2 = 0.17$	$y = 5.94 \times (UMA\text{-}C)$; $R^2 = 0.50$
Body shape		
Carcass	$y = 29.80 \times (DPEL)$; $R^2 = 0.09$	$y = 23.36 \times (LANAL)$; $R^2 = 0.26$
Whole fillet	$y = -0.65 \times (LHA)$; $R^2 = 0.08$	$y = 12.18 \times (LPEL)$; $R^2 = 0.17$
Shank fillet	$y = 9.96 \times (LPEL)$; $R^2 = 0.05$	$y = 9.32 \times (LPEL)$; $R^2 = 0.15$
Three Variables		
Carcass	$y = 15.62 \times (UMA\text{-}D) - 1.02 \times (LHA) + 0.72 \times (LPEL)$; $R^2 = 0.38$	$y = 10.68 \times (UMA\text{-}C) + 11.10 \times (LANAL) + 0.76 \times (LHA)$; $R^2 = 0.54$
Whole fillet	$y = 9.03 \times (UMA\text{-}C) - 0.92 \times (LHA) - 5.00 \times (DPEC)$; $R^2 = 0.31$	$y = -1.95 \times (UMA\text{-}A) + 6.29 \times (UMA\text{-}C) + 4.19 \times (UMA\text{-}D)$; $R^2 = 0.48$
Shank fillet	$y = 4.87 \times (UMA\text{-}C) + 3.30 \times (UMA\text{-}D) - 0.71 \times (LHA)$; $R^2 = 0.31$	$y = -2.10 \times (UMA\text{-}A) + 5.79 \times (UMA\text{-}C) + 2.85 \times (UMA\text{-}D)$; $R^2 = 0.56$

[a]One-variable models with UMA as independent variables are based on data from 51 females and 91 males; all other models are based on data from 43 females and 73 males.

independent variables beyond three resulted in only minor increases in R_2 values. R_2 values for regression equations for predicting meat yield from ultrasound in cattle (Bergen et al., 1997; Perry and Fox, 1997; Moser et al., 1998) and swine (Gresham et al., 1994; Berg et al., 1996; Cisneros et al., 1996) were similar to those we observed for catfish in this study. Bosworth et al. (1997) reported that body shape traits had fairly low correlations ($r < 0.35$) with fillet yield in striped bass hybrids, similar to our results with catfish. Although the percentage of variation in yield traits explained by the regression models developed was only moderate, the data suggest that increased posterior body size and reduced head size are associated with higher meat yield in catfish. Because of the small size of catfish at processing, any errors in cutting and trimming have a major impact on yield traits. Processing errors coupled with potential errors in measurement of ultrasound and body shape traits may limit the accuracy of models for predicting yield in live fish. Future work should be conducted to improve models for predicting yield in live catfish and determining the changes in yield traits following selection for body shape and ultrasound traits correlated with yield.

Implications

The results of this study indicate that ultrasound measurements of muscle area in live fish are moderately correlated with meat yield in farm-raised catfish. A single transverse ultrasound scan explained 40 to 50% and 16 to 23% of the variation in meat yield traits in female and male catfish, respectively. Use of ultrasound imagery and, to a lesser degree, body shape data seem to have potential for predicting fillet yield in live catfish. Comparison of carcass traits, ultrasound images of the muscle area, and body shape between sexes and analysis within each sex indicate that fish with smaller heads and a deeper, thicker bodies posterior to the visceral cavity have higher fillet yield. Selection for this general body type could improve fillet yield. Improvements in prediction accuracy, testing of models developed in this study on independent data sets, and determination of response to selection for increased fillet yield are needed to evaluate the potential for using ultrasound and body shape measurements to improve fillet yield in catfish.

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